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(54) Hottest temperature sensor

(57) A circuit for detecting the temperature of the hottest of a plurality of temperature sensing diodes 1 - 3 has the diodes connected in the same sense in parallel between two conductors 20, 21. A single circuit 4 connected to those conductors is used to make a measurement which is indicative of the temperature of the hottest diode. Preferably the measuring circuit provides first and second current biases from sources 5, 6 to the diodes in a known ratio and the voltages established across the diodes are sampled by switches 13, 14 and capacitors 8, 9 and are subtracted from each other with a differential amplifier 7 to provide a signal proportional to the temperature of the hottest diode. In an alternative arrangement, voltage biasing of the diodes is used and the resultant currents are sampled (Fig. 4).

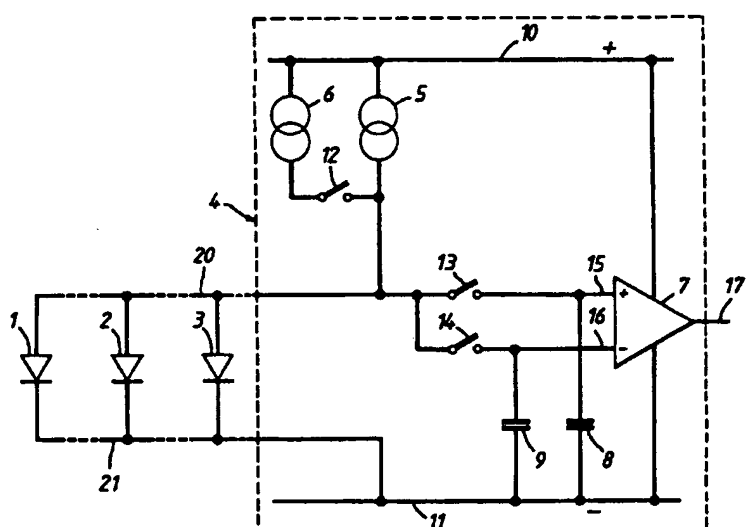

Fig.1

At least one drawing originally filed was informal and the print reproduced here is taken from a later filed formal copy.

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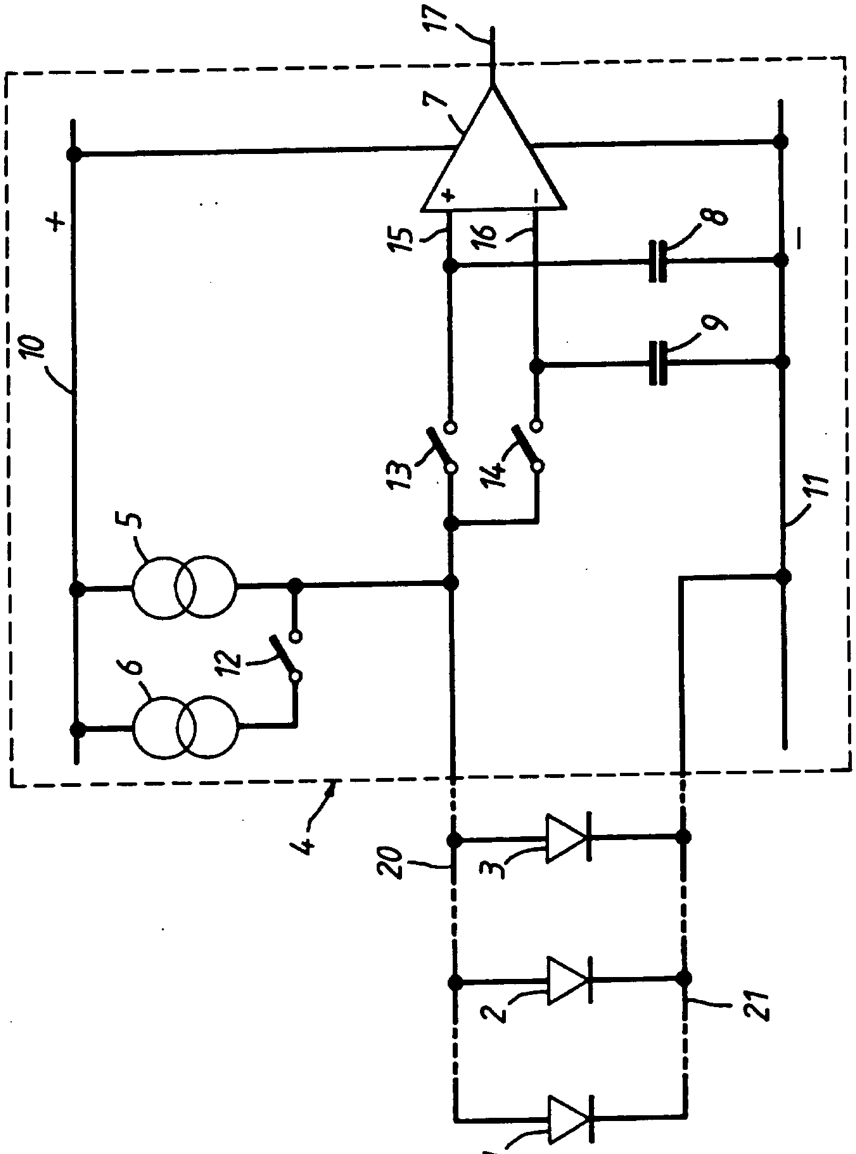

Fig.1

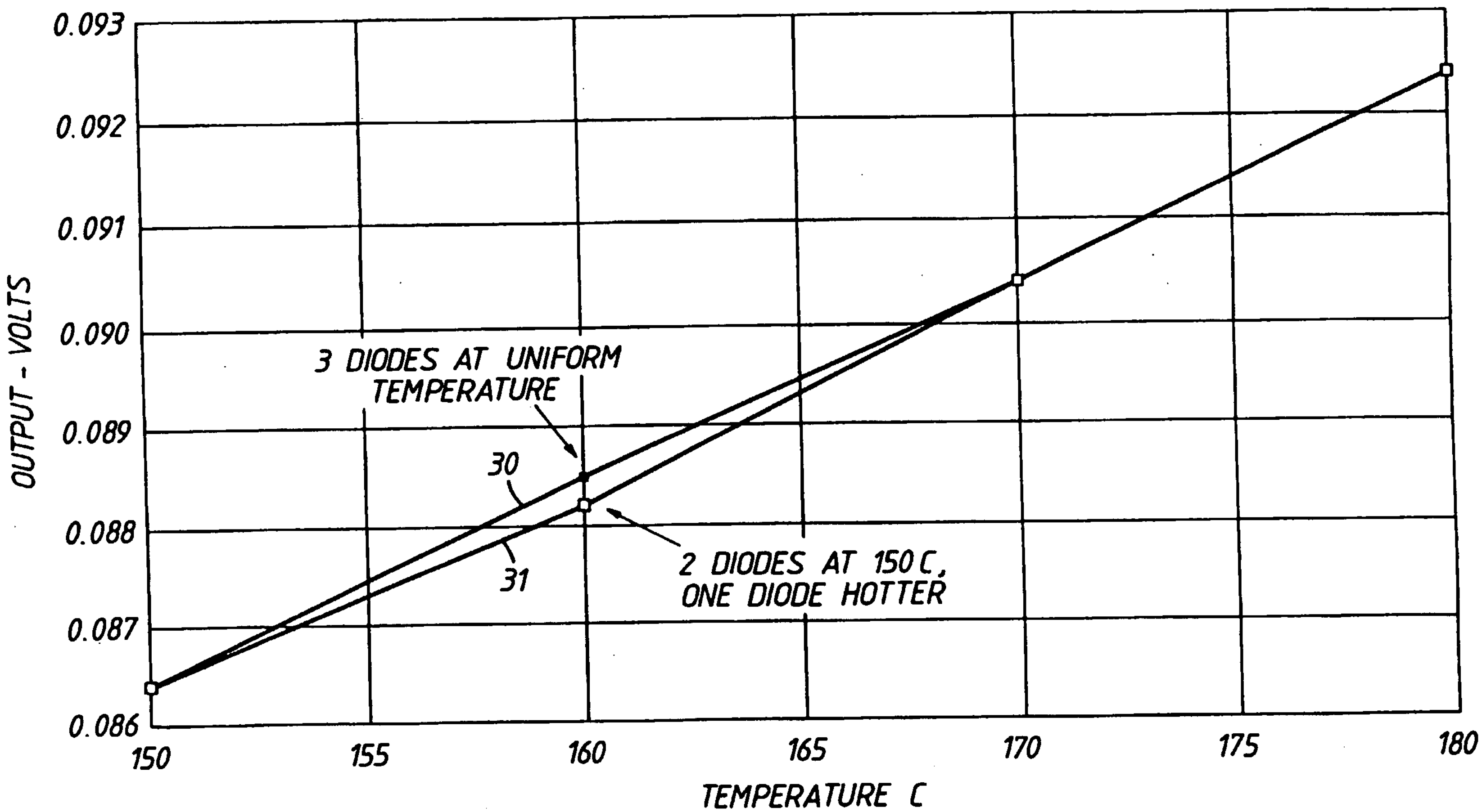
OUTPUT - VOLTS
0.093
0.092
0.091
0.090
0.089
0.088
0.087
0.086
150
155
160
165
170
175
180
TEMPERATURE C
3 DIODES AT UNIFORM TEMPERATURE
2 DIODES AT 150 C, ONE DIODE HOTTER
30
31

Fig.2

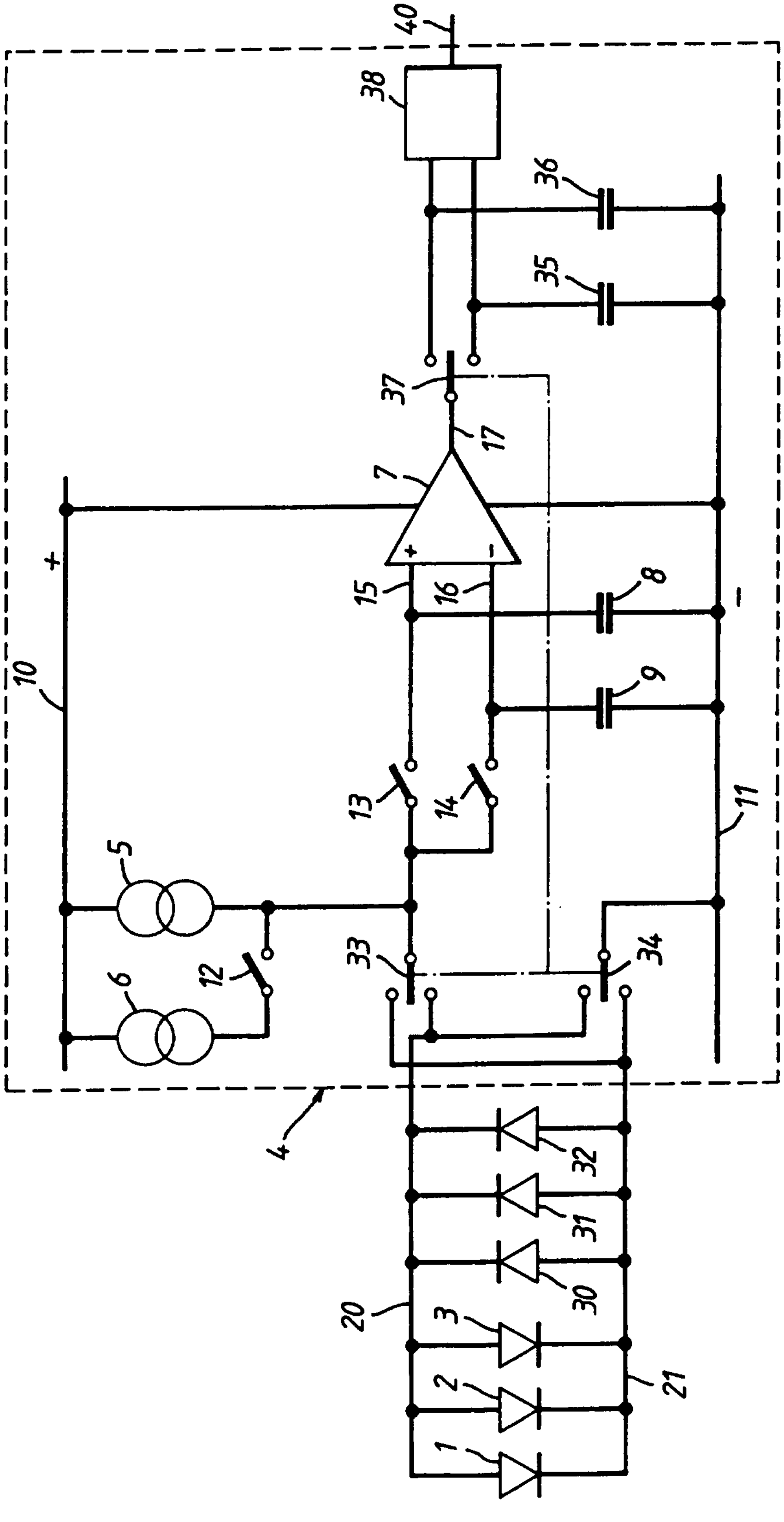

Fig.3

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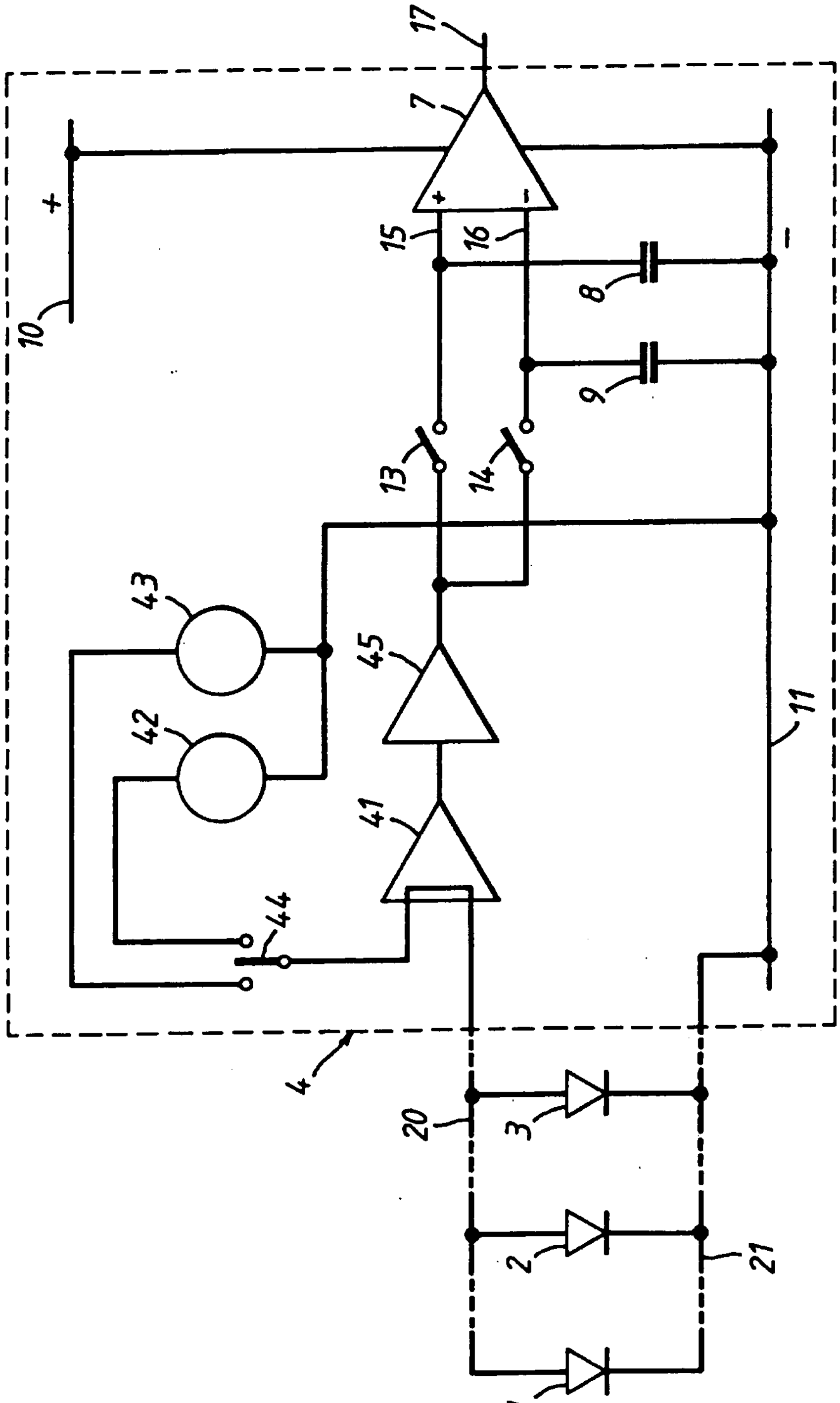

Fig.4

HOTTEST TEMPERATURE SENSOR

The present invention relates to the electronic measurement of temperature with diodes and in particular to providing a measurement of the temperature at the hotter or hottest of two or more different locations.

A measurement of the temperature of the hottest of several locations is of use, for example, in the monitoring of an apparatus which should be turned off when any part of it exceeds a particular temperature.

The present invention provides a circuit comprising a plurality of devices, each including a rectifying semiconductor junction, connected in parallel in the same sense, biasing means connected to the devices for supplying at least a first and a second forward-bias to the plurality of devices as a whole, and measuring means responsive to the electrical response of the devices as a whole to the biases to provide a signal indicative of the temperature of the hotter or hottest of the devices.

The devices are preferably p-n junction diodes and may be, for example, bipolar transistors or Schottky diodes.

The biasing means and measuring means may be provided in the form of an integrated circuit. If so the same pins of the integrated circuit package may be used to connect the integrated circuit to all of the devices. As the devices are connected in parallel, the wiring of the circuit is simple.

The biasing means may be arranged to supply current biases to the devices and the measuring means may be

responsive to the potential difference established across the devices.

The biasing means may be arranged to supply potential difference biases to the devices and the measuring means may be responsive the total current flowing through the devices.

The measuring means may comprise sampling means for sampling the electrical response of the devices at each of two or more discrete biases, or sampling signals derived from those responses, and may comprise comparing means for comparing the samples.

The comparing means may comprise difference means for forming the difference between a first and a second one of the samples.

The biasing means may comprise at least two current sources.

The biasing means may be so arranged that one bias is provided by one but not the other of two of the current sources and that another bias is provided by those two current sources connected in parallel.

The two or more current sources may comprise current mirror means.

The sampling means may comprise switched capacitors connected to receive the potential difference across the devices.

A first capacitor may be connected to receive the potential difference established across the devices when a first current bias is applied and be connected to a

first input of a differential amplifier, a second capacitor may be connected to receive the potential difference established across the devices when a second current bias is applied and be connected to a second input of the differential amplifier, and the differential amplifier may be responsive to its first and second inputs to provide a signal representative of the difference between the potential difference samples held by the first and second capacitors.

While, as a minimum, two discrete samples of the response of the devices to different biases are taken, the measuring means may take into account the response of the devices at further bias points.

The biasing means may comprise means for providing a ramped forward-bias and thus the said first and second forward-biases, and the measuring means may comprise means for differentiating, with respect to time, the electrical response of the devices or a signal derived from that electrical response. The bias may be linearly ramped with respect to time.

The circuit may comprise a second plurality of devices connected in parallel with the first said plurality of devices in the opposite sense to the first plurality, and may be arranged to provide biases of both polarities to the pluralities of devices and to provide respective signals indicative of the temperature of the hotter or hottest device of each of the first and second pluralities.

The circuit may comprise means responsive to the signals indicative of the temperature of the hotter or hottest device of each of the first and second pluralities to provide a signal indicative of the temperature of the hottest device of the first and second pluralities taken together.

The present invention also provides a method of providing a signal indicative of the temperature of the hotter or hottest of a plurality of devices, each including a rectifying semiconductor junction, the method comprising connecting the devices in parallel in the same sense, applying at least a first and a second forward-bias to the plurality of devices as a whole, and deriving the signal indicative of the temperature of the hotter or hottest of the devices from the electrical response of the devices as a whole to the biases.

Current biases may be applied to the devices and the electrical response may be the potential difference established across the devices.

Potential difference biases may be applied to the devices and the electrical response may be the total current flowing through the devices.

The derivation of the signal indicative of the temperature of the hotter or hottest of the devices from the electrical responses of the devices to the biases may comprise sampling the responses of the devices at each of two or more discrete biases or signals derived from those responses and comparing the samples.

The comparing operation may comprise forming the difference between a first and a second one of the samples.

The present invention also provides a method of providing respective signals indicative of the temperature of the hotter or hottest device of first and second pluralities of devices, each device including a rectifying semiconductor junction, the method comprising connecting the devices of the first and the second plurality of devices in parallel with each other, with the devices of the first plurality being connected in the opposite sense to the devices of the second plurality and applying in respect of each of the pluralities a method according to the invention of providing a signal indicative of the temperature of the hotter or hottest of a plurality of devices, to provide the respective signals. There may then be provided, in response to the respective signals indicative of the temperature of the hotter or hottest device of each of the pluralities, a signal indicative of the temperature of the hottest device of the pluralities taken together.

There will now be described, by way of example only, a circuit according to the present invention, with reference to the accompanying drawings of which:

FIGURE 1 is a circuit diagram of a circuit for measuring the hottest temperature of those at three locations.

FIGURE 2 is a graph showing the output of a circuit according to Figure 1 under various conditions.

FIGURE 3 is a circuit similar to that of Figure 1 for measuring the hottest temperature from those at a large number of locations.

FIGURE 4 is an alternative circuit to that of Figure 1.

Figure 1 shows three diodes 1, 2 and 3 connected in parallel in the same sense between a first common conductor 20 connected to the anodes of the diodes and a second common conductor 21 connected to the cathodes of the diodes. The conductors 20 and 21 are connected to an integrated circuit, indicated generally by the reference numeral 4, which includes two current sources 5 and 6, a differential amplifier 7, two sampling capacitors 8 and 9 and positive and negative supply rails 10 and 11. The conductor 21 and the cathodes of the diodes 1, 2 and 3, are connected directly to the negative supply rail 11. The first current source 5 is permanently connected between the positive supply rail 10 and the conductor 20. The second current source 6 is connected to the positive supply rail 10 and via a switch 12 to the conductor 20.

The conductor 20 is also connected to a terminal of each of the sampling capacitors 8 and 9 respectively via switches 13 and 14. Those terminals are respectively connected to positive 15 and negative 16 inputs of the differential amplifier 7. The other terminals of the capacitors 8 and 9 are connected to the negative supply rail 11. An output 17 of the differential amplifier is available for connection to other circuits. The circuit has means, not shown, for operating the switches 12, 13 and 14 in the manner described below.

In operation, initially switches 12 and 13 are open and switch 14 is closed, so that the diodes are biased by the first current source 5 only and the voltage established across the capacitor 9 becomes equal to that across the diodes. Then switch 14 is opened which preserves the first sampled voltage on capacitor 9. Switches 12 and 13 are then closed, so that the diodes are biased by the sum of the currents provided by the two current sources 5 and 6 together and the voltage established across the capacitor 8 becomes equal to the voltage across the diodes. The switch 13 is then reopened to preserve the second sampled voltage on the capacitor 8. The switch 12 is then opened followed by the closing of switch 14 to return to the initial situation. The cycle of switch operations is then repeated.

The above cycle of operations causes the voltage present at the output 17 of the differential amplifier to be maintained at a voltage representative of the

difference between the voltage established across the diodes when they are being biased by the combined current of both sources 5 and 6 and the corresponding voltage when they are biased by the first source 5 only. When one of the three diodes 1, 2 and 3 is hotter than the others, the voltage output from the differential amplifier 7 is indicative of the temperature of that diode despite the fact that that diode, whichever it is, is shunted by two other diodes which are at lower temperatures.

When the diodes are all at the same temperature the voltage output from the differential amplifier is indicative of their temperature. Furthermore the voltage in that case is the same as it would be if the temperature of all but one of the diodes were to be reduced. The output of the circuit therefore indicates the temperature of the hottest of the diodes, even if that is all of them, without its being necessary to know whether one diode in particular is the hottest or whether they are all at the same temperature. The following may help to explain why that is so.

When one of the three diodes 1, 2 and 3 is substantially hotter than the others, substantially all the current from the source 5, or from sources 5 and 6 as the case may be, flows through that diode. The cooler diodes are, therefore, effectively non-conducting. The voltage across the diode is therefore determined by the current passing through the hottest diode.

Now, under conditions of forward bias the current-voltage characteristic of an individual diode can be approximated to the equation:

$$I = I_1(T) . e^{\left(\frac{qV}{kT}\right)} \qquad (1)$$

where I is the current through the diode, V is the potential difference across it, q is the magnitude of the charge of an electron, k is Boltzmann's constant, T is the absolute temperature of the diode and $I_1(T)$ is the leakage current of the diode which is a function of the temperature T of the diode.

Applying equation 1 to the hottest diode for each of the two bias conditions leads to the equation:

$$T_h = \frac{q(V_b - V_a)}{k \, ln\left(\frac{I_{sb}}{I_{sa}}\right)} \qquad (2)$$

where T_h is the absolute temperature of the hottest diode, I_{sa} and I_{sb} are respectively the currents produced by source 5 and by source 5 and source 6 together, and V_a and V_b are the respective voltages established across the diodes in response to the two biases. As may be seen from equation (2), the output of the circuit, V_b-V_a, is proportional to the temperature of the hottest diode.

When the temperatures of the diodes 1, 2 and 3 are all equal equation 1 can be applied to each of the diodes for the two bias conditions, leading to the equation:

$$T_e = \frac{q(V_b - V_a)}{k\,ln\left(\frac{I_{ib}}{I_{ia}}\right)} \qquad (3)$$

where T_e is the absolute temperature of the diodes, i is an index labelling the diodes, I_{ia} and I_{ib} are the currents passing through each of the diodes under each of the bias conditions, and V_a and V_b are the respective voltages established across the diodes in response to the two biases. In this case as well the output of the circuit, V_b-V_a, is proportional to the temperature of the diode.

Now, the currents I_{ia} and I_{ib} are in the same ratio as the currents I_{sa} and I_{sb} from the current sources and so can be substituted for them in equation 3 to give:

$$T_e = \frac{q(V_b - V_a)}{k\,ln\left(\frac{I_{sb}}{I_{sa}}\right)} \qquad (4)$$

which equation has the same right hand side as equation 2. Therefore, not only is the output of the circuit proportional to the temperature of the hottest of or all of the diodes, as the case may be, but the constant of proportionality is the same in both cases.

Clearly the above analysis holds for any number of diodes equal to two or more.

That the ratio of the currents I_{sa} and I_{sb} from the current sources is equal to each ratio of the currents I_{ia} and I_{ib} flowing through the respective diodes in the case of all the diodes having the same temperature may be shown as follows. Applying equation 1 to each of the

diodes when the diodes are biased by each of the currents I_{sa} and I_{sb} gives:

$$T_e = \frac{qV_a}{k\,ln\left(\frac{I_{ia}}{I_{li}}\right)} = \frac{qV_b}{k\,ln\left(\frac{I_{ib}}{I_{li}}\right)} \tag{5}$$

where V_a and V_b are the respective voltages established across the diodes and I_{li} is the leakage current I_l for each diode. Since the temperatures of all the diodes are equal and they have the same voltage across them, then α and β defined as the ratios I_{ia}/I_{li} and I_{ib}/I_{li} respectively, are constants, which leads to:

$$\frac{I_{sb}}{I_{sa}} = \frac{\sum_i I_{ib}}{\sum_i I_{ia}} = \frac{\sum_i \frac{\beta}{\alpha} I_{ia}}{\sum_i I_{ia}} = \frac{\beta}{\alpha} = \frac{I_{ib}}{I_{ia}} \tag{6}$$

Figure 2 is a graph of the output, in volts, of an example circuit of Figure 1 under various conditions of temperature of the three diodes. The circuit used to produce the graph supplied currents to the diodes in the ratio of ten to one and used a differential amplifier with unity gain.

The current biases used were 10 μA and 100 μA respectively. Those biases resulted voltages across the diodes of around 0.4 V at 150 °C. The ratio of 10:1 was chosen because it gives an adequate difference in the voltages across the diodes at the two biases. A larger ratio would give a larger voltage difference; very large ratios, 1000:1 for example, are difficult to provide and the large current may heat the diodes significantly.

A first curve 30 on the graph shows the output of the circuit when the three diodes are at the same temperature as each other, which temperature is given on the abscissa of the graph. A second curve 31 shows the output when two of the diodes are at 150 °C and the other diode is at the temperature given on the abscissa.

As would be expected from the discussion above, the two curves are almost identical.

One or other of the curves 30 and 31 may be used as a calibration curve for the circuit. If curve 30 for the diodes being at the same temperature was chosen then the circuit would read true when that was the case. If, however, one diode was substantially hotter, for example, at 160 °C while the others were at 150 °C (which, as may be seen from curve 31, would produce an output from the circuit of 0.0882V), then, using the chosen calibration, curve 30, the circuit would read 158 °C. That error would be considered negligible in many applications.

In general any number of temperature sensing diodes greater than or equal to two may be employed. If the number is higher than twenty, say, the total of the currents through the cooler diodes will be significant compared to that through the hottest diode. The output of the circuit is then dependent on the temperature of the cooler diodes.

Figure 3 shows a circuit which allows the number of diodes to be increased without greatly reducing the accuracy of the circuit. The circuit of Figure 3 is a

modified form of that of Figure 1 and so similar reference numerals have been used where appropriate. A first plurality of diodes 1, 2 and 3 is connected between the conductors 20 and 21 in one sense and a second plurality of diodes 30, 31 and 32, is connected in the opposite sense. Bias currents of both polarities are provided from the current sources 5 and 6 by means of ganged switches 33 and 34 which swap the connections of the conductors 20 and 21 to the integrated circuit 4. With those switches in one position, the temperature of the hottest diode of one plurality, the plurality that is forward-biased, is measured by the circuit in the same way as the circuit of Figure 1. The other plurality of diodes is reverse biased and so affects the measurement little. The temperature of the hottest diode of the other plurality is measured with the switches 33 and 34 in the other position. The outputs of the differential amplifier 7 for each of the pluralities are respectively stored on capacitors 35 and 36 by means of a switch 37 ganged with switches 33 and 34. A circuit 38 is connected to receive the voltages stored on the capacitors 35 and 36 and outputs the larger of those two voltages on conductor 40. The voltage output on conductor 40 is indicative of the temperature of the hottest diode of the two pluralities taken together.

The circuits illustrated sample the voltages established across the diodes in response to current biases. It is also possible to measure the temperature of

the hotter or hottest of a plurality of diodes connected in parallel in the same sense by applying in turn first and second bias voltages, V_a and V_b, and sensing the total currents, I_{sa} and I_{sb}, respectively flowing through the diodes in response. Equations (2) and (4) show that, in that case, a signal inversely proportional to the temperature of the hottest diode can be formed by forming a signal proportional to $\ln(I_{sb}) - \ln(I_{sa})$. Figure 4 shows a suitable circuit which is a modified form of the circuit of Figure 1; similar reference numerals are used where appropriate. A transresistance amplifier 41 is connected to receive the total current passing through the diodes in response to two voltage biases provided by voltage sources 42 and 43 respectively. The voltage connected to the diodes is selected by a switch 44. The transresistance amplifier converts the currents to voltages which are passed to the input of a logarithmic amplifier 45 . The voltages output from the logarithmic amplifier are sampled using respective capacitors 8 and 9 and the sampled voltages are compared with a differential amplifier 7.

An alternative to discrete biases and samples would be to provide a continuous ramped bias to the diodes and to differentiate a signal obtained from the diodes with respect to time.

In the case of current biasing, the current sources 5 and 6 of Figure 1 or Figure 3, for example, are replaced by a source for providing a ramped current bias

to the diodes and the sampling capacitors 8 and 9 and the differential amplifier 7 are replaced by a differentiating circuit.

In the case of voltage biasing, the voltage sources 42 and 43 of Figure 4, for example, are replaced by a source for providing a ramped voltage bias and again the sampling capacitors 8 and 9 and the differential amplifier 7 are replaced by a differentiator.

In both cases the bias is linearly ramped so that the output of the differentiator is a constant signal proportional and inversely proportional respectively to the temperature of the hottest diode.

CLAIMS:

1. A circuit comprising a plurality of devices, each including a rectifying semiconductor junction, connected in parallel in the same sense, biasing means connected to the devices for supplying at least a first and a second forward-bias to the plurality of devices as a whole, and measuring means responsive to the electrical response of the devices as a whole to the biases to provide a signal indicative of the temperature of the hotter or hottest of the devices.

2. A circuit as claimed in claim 1, wherein the biasing means and measuring means are provided in the form of an integrated circuit.

3. A circuit as claimed in claim 1 or claim 2, wherein the biasing means is arranged to supply current biases to the devices and the measuring means is responsive to the potential difference established across the devices.

4. A circuit as claimed in claim 1 or claim 2, wherein the biasing means is arranged to supply potential difference biases to the devices and the measuring means is responsive to the total current flowing through the devices.

5. A circuit as claimed in any one of claims 1 to 4, wherein the measuring means comprises sampling means for sampling the electrical response of the devices at each of two or more discrete biases or signals derived from those responses and comparing means for comparing the samples.

6. A circuit as claimed in claim 5, wherein the comparing means comprises difference means for forming the difference between a first and a second one of the samples.

7. A circuit as claimed in claim 5 or claim 6, wherein the biasing means is arranged to provide current biases and comprises at least two current sources.

8. A circuit as claimed in claim 7, wherein the biasing means is so arranged that one bias is provided by one but not the other of two of the current sources and that another bias is provided by those two current sources connected in parallel.

9. A circuit as claimed in claim 7 or claim 8, wherein the two or more current sources comprise current mirror means.

10. A circuit as claimed in any one of claims 5 to 9, wherein the biasing means is arranged to provide current biases and the measuring means is responsive to the potential difference established across the devices and wherein the sampling means comprises switched capacitors connected to receive the potential difference across the devices.

11. A circuit as claimed in claim 10 wherein a first capacitor is connected to receive the potential difference established across the devices when a first current bias is applied and is connected to a first input of a differential amplifier, wherein a second capacitor is connected to receive the potential difference established across the devices when a second current bias is applied and is connected to a second input of a differential amplifier, and wherein the differential amplifier is responsive to its first and second inputs to provide a signal representative of the difference between the potential difference samples held by the first and second capacitors.

12. A circuit as claimed in any one of claims 1 to 4, wherein the biasing means comprises means for providing a ramped forward-bias and thus the said first and second forward-biases, and the measuring means comprises means for differentiating, with respect to time, the electrical response of the devices or a signal derived from that electrical response.

13. A circuit as claimed in claim 12, wherein the biasing means is for providing a bias that is linearly ramped with respect to time.

14. A circuit as claimed in any preceding claim comprising a second plurality of devices connected in parallel with the first said plurality of devices in the opposite sense to the first plurality, wherein the circuit is arranged to provide biases of both polarities to the pluralities of devices and to provide respective signals indicative of the temperature of the hotter or hottest device of each of the first and second pluralities.

15. A circuit as claimed in claim 14, comprising means responsive to the signals indicative of the temperature of the hotter or hottest device of each of the first and second pluralities to provide a signal indicative of the temperature of the hottest device of the first and second pluralities taken together.

16. A method of providing a signal indicative of the temperature of the hotter or hottest of a plurality of devices, each including a rectifying semiconductor junction, the method comprising connecting the devices in parallel in the same sense, applying at least a first and a second forward-bias to the plurality of devices as a whole, and deriving the signal indicative of the temperature of the hotter or hottest of the devices from the electrical response of the devices as a whole to the biases.

17. A method as claimed in claim 16, wherein current biases are applied to the devices and the electrical response is the potential difference established across the devices.

18. A method as claimed in claim 16, wherein potential difference biases are applied to the devices and the electrical response is the total current flowing through the devices.

19. A method as claimed in any one of claims 16 to 18, wherein the derivation of the signal indicative of the temperature of the hotter or hottest of the devices from the electrical responses of the devices to the biases comprises sampling the responses of the devices at each of two or more discrete biases or signals derived from those responses and comparing the samples.

20. A method according to claim 19 wherein the comparison comprises forming the difference between a first and a second one of the samples.

21. A method as claimed in any one of claims 16 to 18, wherein a ramped forward-bias is applied to the devices thus providing the said first and second forward biases, and wherein the electrical response of the devices or a signal derived from that electrical response is differentiated with respect to time.

22. A method as claimed in claim 21, wherein the forward-bias applied is ramped linearly with respect to time.

23. A method of providing respective signals indicative of the temperature of the hotter or hottest device of first and second pluralities of devices, each device including a rectifying semiconductor junction, the method comprising connecting the devices of the first and the second plurality of devices in parallel with each other, with the devices of the first plurality being connected in the opposite sense to the devices of the second plurality and applying in respect of each of the pluralities a method as claimed in any one of claims 16 to 22 to provide the respective signals.

24. A method as claimed in claim 23 comprising providing, in response to the respective signals indicative of the temperature of the hotter or hottest device of each of the pluralities, a signal indicative of the temperature of the hottest device of the pluralities taken together.

25. A circuit or a method as claimed in any preceding claim wherein the device or devices are p-n junction diodes or Schottky diodes or bipolar transistors.

26. A circuit substantially as described herein with reference to and as illustrated by Figure 1, or Figure 3, or Figure 4 of the accompanying drawings.

27. A method of providing a signal indicative of the temperature of the hotter or hottest of a plurality of diodes substantially as described herein with reference to and as illustrated by Figure 1, or Figure 3, or Figure 4 of the accompanying drawings.

Patents Act 1977
Examiner's report to the Comptroller under Section 17 23
(The Search report)

Application number
GB 9416101.5

Relevant Technical Fields

(i) UK Cl (Ed.M) G1N (NAAK, NADC, NAFB, NAHHA, NAHHB, NAHHK)

(ii) Int Cl (Ed.5) G01K 7/00

Search Examiner
M G Clarke

Date of completion of Search
28 September 1994

Databases (see below)
(i) UK Patent Office collections of GB, EP, WO and US patent specifications.

(ii) ONLINE DATABASES : WPI

Documents considered relevant following a search in respect of Claims :-
1 to 27

Categories of documents

X: Document indicating lack of novelty or of inventive step.

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E: Patent document published on or after, but with priority date earlier than, the filing date of the present application.

&: Member of the same patent family; corresponding document.

Category	Identity of document and relevant passages	Relevant to claim(s)
A	GB 2222884 A (PHILIPS ELECTRONIC etc) whole document	
A	GB 2109938 A (FERRANTI LTD) whole document	

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